Willingness to pay for electric vehicles and vehicle-to-grid applications: a Nordic choice experiment

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Willingness to Pay for Electric Vehicles and Vehicle-to-Grid Applications: A Nordic Choice Experiment

Lance Noel,*[1] Andrea Papu Carrone[2], Anders Fjendbo Jensen[2], Gerardo Zarazua de Rubens[1], Johannes Kester[1], and Benjamin K. Sovacool[1,3]

[*] Corresponding Author Email: lnoel@btech.au.dk

[1] Center for Energy Technologies, Department of Business Development and Technology, Aarhus University, Denmark
[2] Transport Modelling Division, Department of Management Engineering, Technical University of Denmark, Denmark
[3] Science Policy Research Unit (SPRU), School of Business, Management, and Economics, University of Sussex, United Kingdom

Abstract: We present the results from a choice experiment conducted across Denmark Finland, Iceland, Norway and Sweden focusing on electric vehicles and vehicle-to-grid technology. The survey involved the entire Nordic region and had more than 4,000 respondents choosing between two versions of electric vehicles (some including vehicle-to-grid capability) as well as their preferred gasoline vehicle. We analyzed the data using a mixed logit model and present the willingness to pay for driving range, acceleration, recharging time, fuel source, and vehicle-to-grid capability. In addition, due to the cross-national nature of our data, we also present willingness-to-pay comparisons between the five Nordic countries. We find that certain attributes, like driving range and recharging time, are substantially higher than previous estimates, whereas others, like acceleration are lower. In addition, we find that some attributes vary across the five countries (such as driving range), whereas other attributes remain constant. Finally, we find that vehicle-to-grid capability, divorced of onerous contracts, is significantly positive, but only for some countries, whereas in other countries it has no value, implying greater education and awareness of vehicle-to-grid is necessary if it is to accelerate electric vehicle adoption.

Keywords: electric vehicles; electric mobility; vehicle-to-grid; willingness-to-pay; choice experiment

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1. Introduction

The willingness-to-pay (WTP) for electric vehicles (EVs) has been of keen interest in both academia and policy communities. EVs offer the potential to reduce carbon emissions, improve public health (due to displaced air pollution), and capture other co-benefits, such as increased national and energy security and noise reduction (1–3). In addition, EVs can provide storage to the electricity grid, termed vehicle-to-grid (V2G) capability, which provides additional economic benefits to EV owners, improves grid efficiency, and may help integrate renewable energy (4,5). Nonetheless, EVs have underperformed globally in their implementation to decarbonize transport, with one central barrier being cost (6,7). Thus, assessing the willingness to pay for EVs is essential to better understand the consumer dynamics of a more sustainable transition from internal combustion engine vehicles (ICEVs) to EVs.

As a result, there have been a variety of choice experiment surveys specifically on EVs over the last few decades (8). Though EV technology has developed substantially, most choice experiments focus on attributes of range, price, acceleration, charging availability and recharging time (8–10), with most finding these attributes to be significant. For example, Hirdue et al. found that range anxiety, charging time, and price were the key attributes for consumers, and found that additional driving range of a mile was worth $35-$75, and charging time was worth $425-$3,250 per hour (10). More recently, Helveston et al. compared consumer preferences in the US and China and found significant differences in WTP between the countries, where the average US consumer had a WTP of $10,000-$20,000 less than a conventional vehicle, whereas China the WTP was comparable to a conventional vehicle (11). Beyond traditional choice experiment surveys, there has also been research that explores EV stated preferences in more novel methodologies. For example, there has been research which combined stated preference with revealed preference data (12). In addition, specific to Europe, Jensen et al. conduct a choice experiment gauging WTP before and after experiencing EVs, finding that experience can vastly change individual's preferences for certain EV attributes, such as range (13).

On the other hand, as compared to the wealth of literature focusing on EV choice experiments, there have only been a handful of previous choice experiments that address vehicle-integration and V2G. The only study to explicitly include V2G, Parsons et al., expanded upon the analysis in Hidrue et al. (10) to include V2G in EV choice sets, but is already out of date. Also, in their choice experiment design, they included the following attributes specific to V2G: minimum guaranteed driving range, required plug-in time per day, and annual cash bask payment (14). While the authors importantly find that the contract terms requiring a certain amount of hours on a plug per day were highly inconvenient to drivers, we believe that V2G would not require individuals to sign contracts of that nature (4). Instead, the future of V2G would likely rely on aggregated resources and forecasting rather than burdensome individual contracts. As a result, our study is distinguished from Parsons et al. (2014) in that we do not measure the attributes of V2G *contracts*. Instead, we merely inform the participants of the benefits and costs of V2G capability, and include it as one of our attributes in the general EV choice set.

Secondly, other choice experiments have investigated broader grid integration of electric vehicles. For example, Bailey & Axsen studied the preferences for electric vehicles with utility controlled charging (UCC) and found that acceptance of UCC would vary widely across the population (15). Indeed, while some of the respondents in their survey would offer their EV to help the grid at little to no cost, others were very skeptical of outside control of their EVs, and would require high compensation for such services. However, our study here focuses on bidirectional participation of frequency regulation and other ancillary services, which is a more socioeconomically valuable service than controlled charging to both the user and society (4,16), and is currently being tested in V2G pilot projects (14).

As compared to the current literature, our research offers several novel contributions. First, in a recent systematic review of alternative-fuel vehicle (AFV) choice experiments, only two studies from 2005 to 2015 included more than one country (8,11,17). These studies only compared two countries, whereas the choice experiment we present below compares five countries across an entire region. Indeed, given wide disparity between EV policies across the five Nordic countries, particularly between countries like Norway and Denmark or Finland, we can determine how the differing background settings of each country affects relative WTP of EVs and V2G. Secondly, we present novel results on the preferences of electricity sources for recharging EVs, finding consumers, somewhat irrationally we argue, to highly value non-fossil fuel and non-nuclear sources when choosing EV, well beyond typical refueling prices or previous estimates of consumer WTP for cleaner electricity sources. Thirdly, in addition to presenting more typical experiment results about EVs, we also present novel choice experiment results on consumer's V2G preferences. Rather than gauge preferences on V2G contracts, we measure the preferences for V2G capability, finding that there is great variability in WTP between countries.

2. Survey Choice Experiment Design & Distribution

We used an internet-based survey, which ran from September 2016 to November 2017. In the months before the launch of the survey, we pretested the survey with local populations as well with several survey design and subject matter experts, and made several improvements to the design, structure, and language of the survey.

The finalized survey contained four sections, including: i) Vehicle History & Background, ii) Vehicle Preferences, iii) Electric Vehicle Choice Experiment, and iv) Demographics. The first section of the survey includes questions about prior vehicle ownership and general transport history, and planned vehicle purchases. Included in this section was a question gauging the respondent's prior knowledge of V2G. Next, the second section of the survey asks the respondent to rank the importance of various general vehicle and electric vehicle specific attributes in Likert scales. Thirdly, the choice experiment was designed in JMP using orthogonal design, and blocked into 10 sections, each of which contained 6 choice sets within each block, based on the potential cognitive burden of an increased numbers of choice sets (18). Prior to the actual experiment, the concept of V2G was described to the respondents again, posed with two benefits (provides car owners a monthly revenue and makes the electricity grid more efficient and cleaner) and two costs (requires car owners to plan each trip they take and potential minor to moderate battery degradation). An example of one of the choice sets is shown in Figure 1. Each choice set included two electric vehicles and an opt-out, which we termed as their "preferred petrol vehicle". Finally, the survey concludes with some demographic data, including attitudinal questions on the environment.

Attributes	**Electric Vehicle 1**	**Electric Vehicle 2**	

Driving Range (*in km*)	250	150	**Your Preferred Petrol Vehicle**
Acceleration (*0-100 km/h, in seconds*)	4	7	
Recharging Time	8 hours	1 hour	
Fuel Type (*electricity source*)	Renewables	Fossil Fuels	
V2G-Capable	Yes	Yes	
Price (*in €'s*)	65,000	30,000	

Figure 1. Example of Choice Set Presented to Respondents

The choice experiment was designed principally with five attributes: driving range, acceleration, recharging time, fuel type, and V2G capability. The levels of each of the five attributes and the price of the vehicle are presented in Table 1. The first three attributes (range, accelerations, and recharging time) were chosen as we believed these were the most important attributes of an EV (8), and based on historical and near-future estimates. We also added Fuel Type (i.e., electricity source) as an attribute to measure how consumers valued (or did not value) the source of electricity for their potential EV, including renewables, nuclear, hydro, and fossil fuels, note that we did not distinguish between wind and solar nor between coal and natural gas. Though one does not actually choose their electricity source, the hypothetical choice was intuitively understood during the pre-testing, and we received no comments expressing confusion at this choice. Finally, we also include V2G-capability, however unlike previous V2G choice experiments we only include a yes or no option, removing restrictive contract terms. Instead, before the choices were presented, we reminded the respondents of V2G's benefits (financial compensation and increased electricity grid efficiency) and costs (further requisite trip planning and minor to moderate impacts on battery life).

Attribute (units)	Levels
Driving Range (in km)	150 200 250 300 400

Acceleration (0-100 km/h, in seconds)	4 6 7 8 10
Recharging Time	8 hours 4 hours 2 hours 1 hour 30 minutes
Fuel Type	Renewables Fossil Fuels Nuclear Hydro
V2G-Capable	Yes No
Price (in €'s)	18,000 26,000 30,000 34,000 45,000 52,000 65,000 80,000

Table 1. Levels for Each Choice Experiment Attribute

The survey was distributed both in a randomized sample, as well as a non-random convenience sample. The randomized sample was collected by Qualtrics (a survey generation and distribution company (19)) across the five countries, with the aim to be representative of the Nordic populations at large in age, country and gender. Respondents had to be over the age of 18 years old. There was a total of 4,602 responses completed in the random sample, nearly evenly distributed across the four countries (slightly less were completed in Iceland, due to the difficulty of reaching respondents). In addition, we also conducted a non-random sample to target specific populations that difficult for the random sample to cover, such as populations in Iceland, current EV owners, and those that had sold their EV (among others). The non-random sample included 1,292 completed surveys, and when combined with the randomized sample, the total response is 5,894 responses. However, many of the surveys were only partially filled in, particularly within the non-randomized convenience sample. When excluding surveys that were redundant, incomplete, and those respondents who did not own a driver's license, the final sample size included 4,105 completed surveys, of which 86% was the randomized sample and approximately evenly distributed among the five Nordic countries. Appendix 1 offers more detail about the specific demographics of the sample by age and gender.

3. Model Specification

The discrete choice model used is jointly estimated on five panel stated choice datasets that correspond to each of the five countries. The model is a mixed logit model (20) that allows to account for panel correlation among choices from the same respondent in the SC dataset. The joint estimation of the model allows controlling for scale differences between the five datasets and therefore, also for direct comparison of individual preferences across the five countries. In the discrete choice model, respondents choose one of the three vehicles offered in the choice experiment (two electric and one petrol). Using the respondents preferred petrol vehicle as the opt-out alternative and letting the EV depend on the vehicle attributes in the experiment, the utility specification is defined in Equation 1:

$$U_{ins}^{c} = \theta(ASC_i^c + \beta_{iX}^c X_{ins} + \beta_{iT}^c T_n + \mu_{in}^c + \varepsilon_{ins}^c)$$

$$U_{0ns}^{c} = \theta(\mu_{0n}^c + \varepsilon_{0ns}^c)$$

Equation 1. Utility Specification Equation

Where U_{ins}^c is the utility that each respondent n from country c associates to alternative i, in the choice scenario s. X_{ins} is the vector of all the vehicle attributes used in the choice experiment: purchasing price, driving range, acceleration, recharging time, fuel type and vehicle-to-grid capability; and T_n is a vector of individual background characteristics. β_{iX}^c and β_{iT}^c are the vectors of coefficients associated with the variables and ASC_i^c are the alternative specific constants. The μ_{in}^c are error components, normally distributed (with mean zero and standard deviation σ_μ^c) across individuals. Finally, the ε_{ins}^c are random terms distributed identical and independently extreme value type 1 for each country, while $\theta = \sigma^c/\sigma^{c_{ref}}$ is a scale parameter that is equal to the ratio of the standard deviations of ε_{ins}^c. θ is restricted to 1 for one of the countries that is selected as reference level (c_{ref}). This causes the error variances in the five datasets to be equal, allowing to merge the five datasets and estimate a joint model.

Respondents are presented with the same SC design in each of the five countries and therefore, the vehicle attributes are the same across all countries. However, their coefficients are allowed to vary in order to test if preferences for different characteristics of EVs are different. For estimation purpose of a joint model, at least one of the β_i^c must be included as a generic coefficient across the five countries.

4. Model Results & Discussion

After filtering for data quality, the final sample size is 4,105 individuals, approximately evenly distributed among countries is acquired. Since each of the individuals answered six choice scenarios, the final dataset of 24,630 observations is available for estimation purposes. Table 2 shows the responses to all our choice experiment questions. There is overall a tendency towards choosing EV alternatives, the average split for EV and petrol vehicle is 61 – 39. Additionally, there are noticeable differences in the overall EV tendency between the countries, as countries like Finland have substantially less preference for the EV alternatives as compared to say Norway and Iceland. Surprisingly, Iceland has the highest preferences for the EV over the petrol vehicle, even over Norway.

	Choices among alternatives			Split EV - PV	
Country	Electric Vehicle 1	Electric Vehicle 2	My preferred petrol vehicle	EV 1 or 2	My preferred petrol vehicle
Denmark	24.5	33.6	41.9	58.1	41.9

Finland	23.4	30.4	46.3	53.7	46.3
Iceland	30.2	39.1	30.7	69.3	30.7
Norway	27.1	34.9	38.0	62.0	38.0
Sweden	25.5	35.4	39.1	60.9	39.1
Average	26.1	34.7	39.2	60.8	39.2

Table 2. Distribution of choices among alternatives

In order to give a sense of the typical EV shown to and chosen by the survey respondent, Table 3 shows the distribution of the EV attributes presented in the choice experiment question, as well as the distribution of the attributes of the EVs that were selected over the preferred ICEV by the respondents. The selected EVs tended to be cheaper, have longer driving range, and recharged faster than the total EVs presented. On the other hand, V2G capability and acceleration tended to have a smaller difference between the two sets.

		All choice experiment questions					Selected alternative in each question				
Variable	*Unit*	N	Mean	Std Dev	Minimum	Maximum	N	Mean	Std Dev	Minimum	Maximum
Purchasing Price	€	49,260	42,746	18,789	18,000	80,000	14,810	37,562	16,878	18,000	80,000
Driving Range	*km*	49,260	263	88	150	400	14,810	282	89	150	400
Acceleration	*seconds*	49,260	7.2	2.1	4	10	14,810	7.3	2.1	4	10
Recharging Time	*hours*	49,260	3.0	2.7	0.5	8	14,810	2.7	2.5	0.5	8
Fuel Type		49,260	2.5	1.0	1	4	14,810	2.3	1.1	1	4
V2G-capable		49,260	0.4	0.5	0	1	14,810	0.4	0.5	0	1

Table 3. Distribution of EV attributes presented/selected in the choice experiment questions

Using mixed logit, a model is estimated with parameters shown in Table 4. For estimation purpose of a joint model, purchase price is included as a generic coefficient across the five countries that is assumed to have a linear effect. Non-linear specifications for driving range and recharging time have been tested. A logarithmic specification for driving range and a linear-logarithmic form of the recharging time showed the best fit. Both fuel type and V2G capability are specified as dummy variables, with the reference level for fuel type are fossil fuels and V2G capability is not capable.

The final model includes individual background characteristics that account for sociodemographic information (age and households with children), car availability and use (average car use in kilometers and household car availability), previous experience driving an EV and previous knowledge about V2G capability. Gender was initially included in the model and was found not significant for all five countries indicating that there is no difference in the preferences towards EV within sexes. Age groups are included as dummy variables in the model, after previous testing the age group under 30 years is included in the model as a dummy, with the reference level for age being adults over 30 years. Households with children, previous experience driving an EV and knowledge about V2G capability are specified as dummy variables where the reference level in all three cases is the negative response. Household car availability is specified as a three-level dummy variable, with the reference level being no cars available in the household. Car usage, which considers the average travelled kilometers per day, is included in the model with a logarithmic specification since it showed a better fit than the linear effect.

We tested various specifications for the model, with the resulting optimum model presented in Table 4. Each of the parameters were tested for significant difference across the five countries, and those that were found not to be significantly different at a 5% level were constrained to be generic across the countries. The attributes were found to be insignificantly different from only some of the other countries. Consequently, as shown in Table 4, the attributes are generic for only some of the countries (e.g. driving range). In addition, the difference between renewable and hydro as a fuel type is found to be statistically insignificant for Iceland, Denmark and Finland, and thus only one unique coefficient is estimated for these countries.

In order to investigate the differences in preferences towards V2G capability of EVs between individuals who were already familiar with the concept before the survey and those who were not, an interaction term of the V2G experiment attribute and the dummy variable accounting for previous knowledge about V2G was included. This interaction was not found significant in any of the five countries meaning that willingness to pay for V2G capability is not significantly different within individuals who were familiar with the concept before the survey and those who were not.

Next, we included the scale parameter θ that allows for heteroscedasticity between countries and is estimated with reference to Norway. The results show that the scale parameter for Iceland is not significantly different from one, confirming that these two datasets have the same variance. Conversely, the scale parameter is found to be significantly different from one for the datasets of Denmark, Sweden and Finland. In addition, the standard deviation that accounts for a panel effect is significant in all the datasets indicating that there is indeed heterogeneity across individuals in all countries. Finally, the alternative specific constants with exception of Sweden are positive and significant, indicating that there is some positive effect for the two EV alternatives that we are not accounting for with the attributes.

	Country				
Variable	Norway	Iceland	Denmark	Sweden	Finland
Alternative specific constant (ASC_{EV})	1.170 **	1.990 ***	0.670 ***	0.216	0.498 **
	(2.25)	(3.21)	(2.95)	(0.87)	(2.41)
Standard deviation for panel effect (σ_{EV})	3.890 ***	2.780 ***	2.890 ***	2.900 ***	2.130 ***
	(19.63)	(10.31)	(11.26)	(11.49)	(11.00)
Purchase Price (EV) [10.000€]	-0.263 ***	-0.263 ***	-0.263 ***	-0.263 ***	-0.263 ***
	(-17.12)	(-17.12)	(-17.12)	(-17.12)	(-17.12)
Acceleration (EV) [0-100 kmph, in seconds]	0.009	-0.023 ***	-0.023 ***	0.009	-0.023 ***
	(0.85)	(-3.06)	(-3.06)	(0.85)	(-3.06)
Driving Range (EV) [100 km]					
Logarithmic	1.190 ***	1.190 ***	0.858 ***	0.858 ***	0.690 ***
	(15.01)	(15.01)	(11.90)	(11.90)	(9.74)
Recharging Time (EV) [hours]					

Linear	-0.044 ***	-0.044 ***	-0.044 ***	-0.074 ***	0.001
	(-3.08)	(-3.08)	(-3.08)	(-3.48)	(0.07)
Logarithmic	-0.157 ***	-0.157 ***	-0.157 ***	-0.041	-0.186 ***
	(-3.76)	(-3.76)	(-3.76)	(-0.67)	(-3.86)
Renewable Fuels (EV) [dummy]	0.672 ***	0.644 ***	0.428 ***	0.672 ***	0.428 ***
	(12.37)	(7.36)	(9.97)	(12.37)	(9.97)
Hydro Fuels (EV) [dummy]	0.584 ***	0.644 ***	0.428 ***	0.584 ***	0.428 ***
	(10.26)	(7.36)	(9.97)	(10.26)	(9.97)
Nuclear Fuels (EV) [dummy]	0.032	-0.477 ***	-0.176 ***	0.032	0.032
	(1.01)	(-5.67)	(-3.06)	(1.01)	(1.01)
V2G Capable (EV) [dummy]	0.137 **	0.015	0.015	0.015	0.110 ***
	(2.42)	(0.54)	(0.54)	(0.54)	(2.93)
Age (under 30) [dummy]	1.450 ***	0.308*	1.450 ***	1.450 ***	0.308*
	(7.66)	(1.87)	(7.66)	(7.66)	(1.87)
Car Use (average kilometers driven per day)					
Logarithmic	0.021**	0.021**	0.021**	0.021**	0.021**
	(2.01)	(2.01)	(2.01)	(2.01)	(2.01)
Single car household [dummy]	-2.010 ***	-1.250 **	-0.676 ***	-0.676 ***	-0.676 ***
	(-3.74)	(-2.04)	(-3.42)	(-3.42)	(-3.42)
Multiple car household [dummy]	-2.590 ***	-1.230 **	-0.840 ***	-0.840 ***	-0.840 ***
	(-4.53)	(-2.02)	(-3.73)	(-3.73)	(-3.73)
Household with children [dummy]	0.822 ***	0.001	0.001	0.822 ***	0.001
	(3.98)	(0.01)	(0.01)	(3.98)	(0.01)
Experience driving EV [dummy]	1.440 ***	0.707 ***	0.707 ***	0.707 ***	1.440 ***
	(6.77)	(3.95)	(3.95)	(3.95)	(6.77)
Previous knowledge of V2G [dummy]	0.122	0.122	0.433 **	1.190 ***	0.433 **
	(0.42)	(0.42)	(2.25)	(3.09)	(2.25)
Scale between countries (Θ) [a]		1.10	1.26 ***	1.32 ***	1.74 ***
		(1.14)	(2.71)	(3.35)	(5.40)
Number of observations					24,630
Number of individuals					4,105
Number of draws					1,000
Number of estimated parameters					52
Log likelihood					-18,744
Null Log likelihood					-26,967
rho-square-bar					0.303

* significant at 10% level; ** significant at 5% level; *** significant at 1% level

[a] t-test against 1

Table 4. Parameter estimations

In Table 4, the significant coefficients have the expected sign. In particular, purchase price and recharging time are negative, as an increase in any of these attributes makes the EV less attractive to the consumer. On the other hand, the coefficients of range, renewable fuel source, hydro fuel source, and vehicle-to-grid (V2G) capability are positive, as consumers prefer EVs with higher range, clean electricity sources and V2G capability. Interestingly, the sign of the nuclear fuel source coefficient depends on the country as Iceland and Denmark have a negative sign, and the others have a very slightly positive sign (as compared to the reference level of fossil fuels), though only the negative coefficients are significant. Given the assumption that consumers value faster acceleration, acceleration (measured as the number of seconds it takes to accelerate from 0 to 100 km/h) presents a negative sign for Denmark, Iceland and Finland, as was expected, although the statistical effect is relatively small. Moreover, the acceleration attribute is not significant for Norway and Sweden.

In the estimation results, young individuals (under 30 years) and households with children have a positive effect for the EV choices. Indeed, as shown in Table 4 above, many of the sociodemographic attributes, keeping in mind gender was excluded from the model due to insignificance, had varied levels of statistical significance across the five countries, corroborating recent literature review finding mixed relevance of sociodemographic attributes (8). The coefficients for households owning one car and multiple cars are negative compared to the reference level of no cars as they are more reluctant to change their already owned car for an EV than those who do not own a car and consider buying. As one might have expected, the effect of car use is negative as individuals who drive longer distances are more concerned about the driving range limitation of EVs. Having previous experience driving an EV has a positive and very significant effect for EV choices in all five countries. The effect of being familiar with the concept of V2G capability is also positive, although statistically less significant. The possible correlation between having experienced driving an EV and previous knowledge about V2G could explain the low statistical significance of the latter specifically in Norway and Iceland, which are the two countries with higher shares of EVs.

Additionally, we converted the significant EV parameter estimates into marginal WTP by dividing the marginal utility of each EV attribute by the marginal utility of purchase price. Each of the WTP for the EV attributes are presented in Table 5, per country.

	Country					
Variable	Norway	Iceland	Denmark	Sweden	Finland	Unit
Driving Range (EV)						
150	302	302	217	217	175	€/km
200	226	226	163	163	131	€/km
250	181	181	130	130	105	€/km
300	151	151	109	109	87	€/km
400	113	113	82	82	66	€/km
Acceleration (EV) [0-100 kmph, in seconds]		-875	-875		-875	€/s

Recharging Time (EV) [hours]						
8	-2,419	-2,419	-2,419	-3,009	-846	€/hour
4	-3,165	-3,165	-3,165	-3,203	-1,730	€/hour
2	-4,658	-4,658	-4,658	-3,593	-3,498	€/hour
1	-7,643	-7,643	-7,643	-4,373	-7,034	€/hour
0.5	-13,612	-13,612	-13,612	-5,932	-14,106	€/hour
Renewable Fuels (EV) [dummy]	25,551	24,487	16,274	25,551	16,274	€/unit
Hydro Fuels (EV) [dummy]	22,205	24,487	16,274	22,205	16,274	€/unit
Nuclear Fuels (EV) [dummy]		-18,137	-6,692			€/unit
V2G Capable (EV) [dummy]	5,209				3,802	€/unit
Constant (EV)	44,487	75,665	25,475		18,935	€/unit

Table 5: WTP for marginal attribute increase, per country

As expected, driving range is an influential attribute in the valuation of EVs by consumers (13). The average marginal WTP for increased range across all five countries, approximately €150/km, is substantially higher than other estimates, such as Hidrue et al., who found a WTP of an equivalent of €38/km in the US (10). Interestingly, our estimates here are much closer to a previous Danish study's estimate of WTP for range *after* they experienced EV driving (an average €134/km for a single-car household), whereas the WTP before experiencing an EV was nearly half of this value (€65/km) (13). Finally, the estimates are also similar to the WTP reported by a more recent choice experiment in Germany, which found WTP values of approximately €95-125/km (21). Thus, it may be that increased awareness of EVs has led the average Nordic consumer to value certain attributes of EVs more significantly, and arguably more accurately.

There is also substantial variation across the countries, as the results show that the consumers in Norway and Iceland attach nearly twice as much importance to driving range than those in Finland. Curiously, the WTP for increased driving range has little connection to the average daily driving distances per country. For example, though the average Finn drives an additional 11 kilometers per day than the average Norwegian (22), Norwegians significantly valued driving range more. Likewise, Swedes drove the least, though they along with Danes had medium WTP values for driving range. Thus, instead, we also theorize that the higher importance of driving range in certain countries is more related to awareness and background EV context of the five countries. That is, Norway leads the way on EVs and Iceland has experienced a peak of sales recently, with market share doubling each of the last 4 years (23). Meanwhile, Denmark and Finland have comparatively minor market for EVs, with Sweden being in the middle, mirroring the WTP estimates more closely than average kilometers driven per day. Therefore, increasingly high valuation of driving range may be a result of historical and geographically-dependent experience and focus on EVs. If the case, then low estimates such as Finland's €92/km should be approached with skepticism, as this value may drastically increase once EVs become more mainstream and Finnish consumers become more aware of the technology.

In addition, we present marginal WTP for EV range in Figure 2 using a non-linear specification of range, providing different WTP per each of additional km range. Unsurprisingly, the WTP for a marginal km of range decreases as the range of EVs increases, implying decreasing marginal value of range at higher values. That is, the 151st km in range is worth substantially more than the 401st km to consumers. On average, and as can be seen in Figure 2, consumers are willing to pay €242 for the 151st km, and only €91 for the 401st km. While the five countries have different WTP values, the overall shape of the curves are essentially the same between all countries. WTP values peak at 150 km, declining rapidly to 300 to 400 km, slowly decreasing for ranges above 400 km (and between-country differences of WTP also diminish). Clearly, a range of 300 to 400 km is most palatable to consumers, though such a range is well above what is sufficient (only 200 km would cover an average of 97.4% trips across Nordic consumers) (22), even when accounting for psychological range anxiety buffers (on average, about 14 km) (24). In other words, following the literature on range sufficiency (e.g. (25,26)), one would expect WTP to sharply decrease after approximately 220 km, but this is not the case. On the other hand, other studies have found that consumers continue to demand range beyond what would be considered sufficient (27–29), as our results corroborate—the marginal WTP for an additional km in EV range even at 400 km is well above previous generic estimates (13,21), showing that strong consumer preferences for additional range continue to persist, even at high ranges. Future research should more thoroughly investigate potentially irrational consumer demand for range.

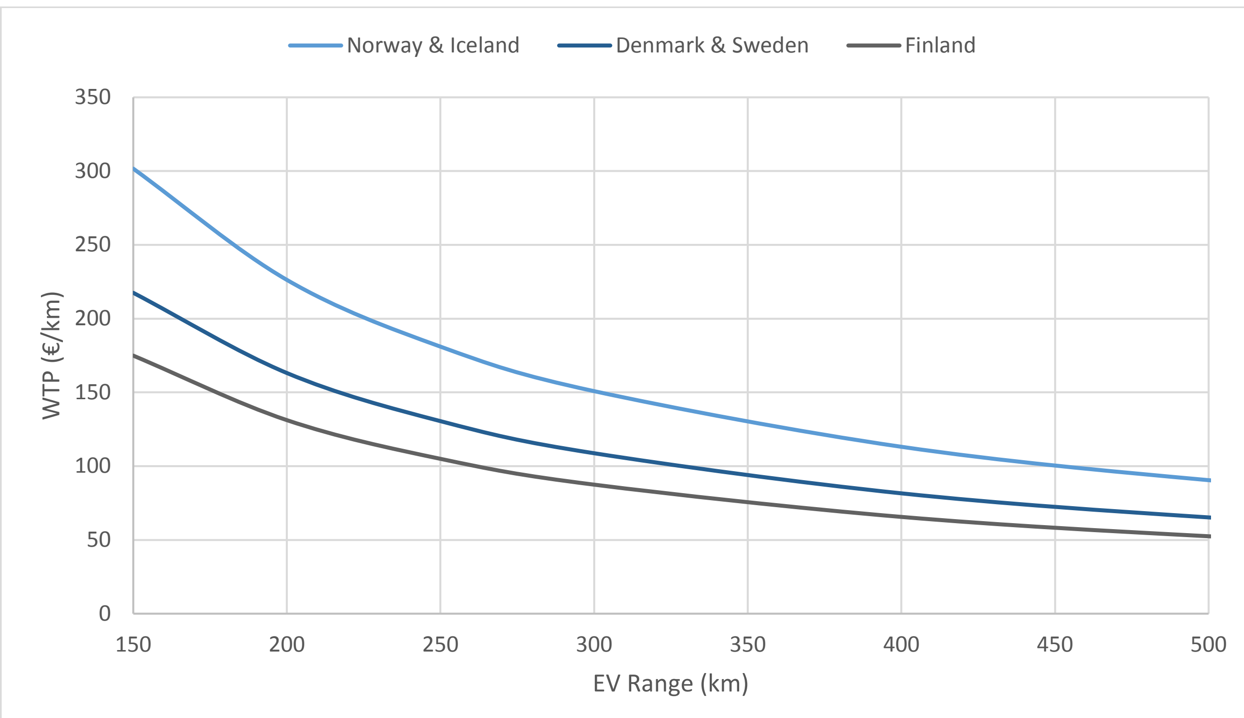

Figure 2. Marginal WTP Per Country for Increases in EV Range

Next, we find that consumers are willing to pay just under €900 for every second reduced in accelerating from 0 to 100 km/h, but only for Iceland, Denmark and Finland (acceleration was not significant for Norway and Sweden, for which we offer no hypothesis). As such, we find that improved acceleration and performance of the vehicle is of lesser importance. Conversely, Hidrue et al. found that going from 20% slower than the respondent's preferred ICEV to 5% faster or 20% faster increased WTP by €4,100 or €5,900, respectively, and concluded that improved performance "noticeably increases the value of an EV" (10). Our different conclusions may come from cultural differences, as Americans may value acceleration more than Nordics. On the other hand, perhaps it is because Hidrue et al. posed the choice as comparative to ICEVs, and consumers are less willing to have a *worse* performing EV, while they are not actually aware of what this would translate to in actual acceleration, in seconds to reach 0-100 km/h. Future research should test this assumption, as it could affect marketing of EVs – either acceleration in the Nordics is unimportant, or it is important but should be framed as comparatively better than ICEVs.

Also expectedly, we find that recharging time has a high WTP, with the countries valuing an hour's reduction in charging time by an average of €5,600, though this is clearly influenced by very high WTP for the shortest recharging time. The average WTP per hour of reduction time only including 2, 4, and 8 hour charging time results in just over half the average value, approximately €3,100. Even this value is at the higher range of previous literature, where lower values were closer to €340- €540/hour, and higher values were still under this average, €2,600-€3,330/hour (10,21). Obviously, the higher average including 1 hour and 30 minute recharging time is substantially higher than previous estimates. Again, we believe that these higher values may be the result of consumers becoming more demanding of EVs as they become more familiar with the technology, as well as the technology itself improving. That is, improvements to charger quality and standards have made an 8 hour re-charge time much more unacceptable to the average consumer as compared to a couple years ago.

We also present the marginal WTP per country in Figure 3. As shown above in Table 5, the valuation of a reduction in charging time below 2 hours is substantially higher than the hourly reduction from 8 hours down to 2 hours. Though fast chargers are infrequently used, and this may be a result of consumer's under-estimating their willingness to instead charge at home for extended periods (e.g. 3-4 hours), OEMs and policymakers may want to better advertise the potential quickness of DC charging. Curiously, Sweden has a substantially different curve as compared to the four Nordic countries, as it is substantially less steep below 1 hour, but also higher above 2 hours.

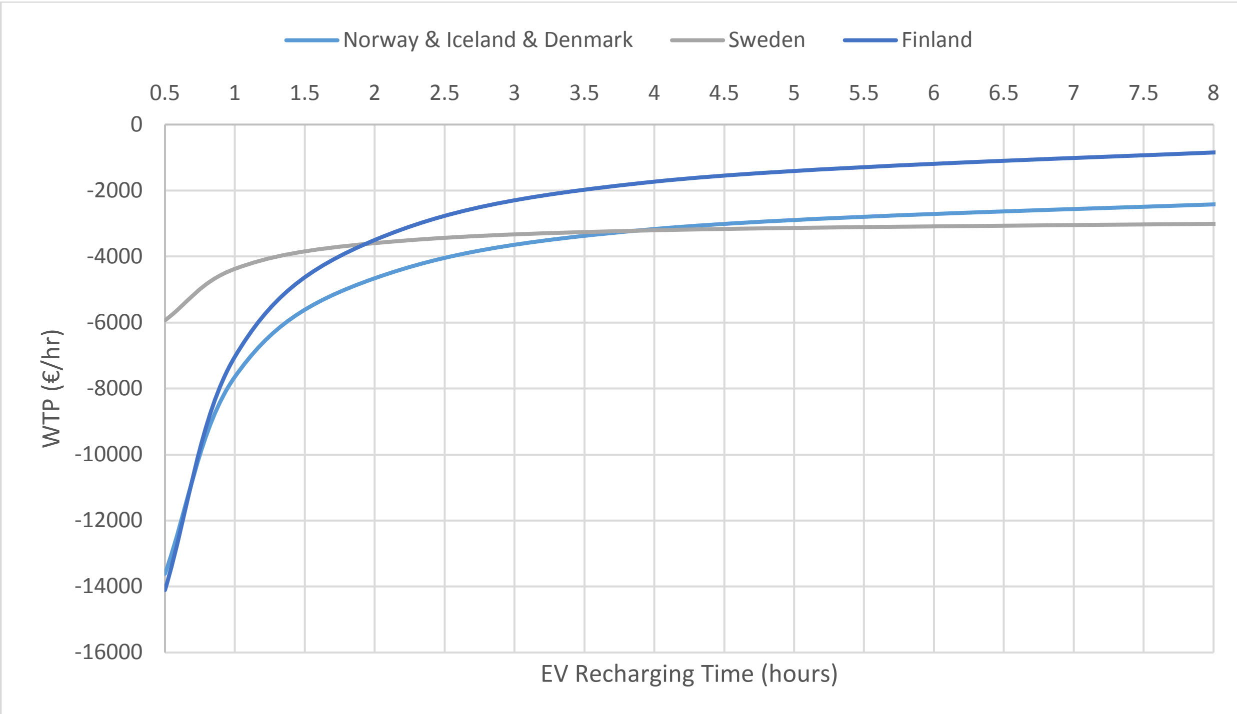

Figure 3. Marginal WTP Per Country For Reduction in EV Recharging Time

Moving beyond attributes specific to EVs, the sourcing of electricity to recharge EVs has a large value to consumers. Indeed, the average consumer is willing to pay an additional €16,000 to €25,500 for an EV that is exclusively recharged with renewables or hydropower electricity, making this attribute one of the most important in the choice experiment. Assuming an approximate 10 year lifespan of a consumer's vehicle, and a consumer-based implied discount rate of 15% (30,31), this is roughly equivalent to €3,400 to €5,200/year (much higher than average yearly petrol costs, which would be about €1,000 to €1,300/year (32)). And assuming an average travel demand of 40 km/day (22) and an estimated vehicle efficiency of 0.2 kWh/km, the WTP premium to source their electricity from clean sources is €1.20 to €1.80/kWh, substantially higher than current electricity prices in the region, as well as substantially higher than previous estimates from electricity-focused choice experiment (33–35). Thus, either consumers are implicitly calculating the premium over a longer period of time than ten years and a very low discount rate (which we think is unlikely as it would take a life span well over 20 years and a discount rate under 3%), or more likely, consumers are overestimating their actual WTP because of a "warm glow" effect. That is, consumers are more likely to choose the greener EV, no matter the cost, as it reinforces that they are "doing the right thing" by improving society in the hypothetical situation that does not actually cost them anything, especially considering meager WTP for renewable electricity in other contexts. Nonetheless, it may behoove policymakers to capture the warm glow effect in real life, by encouraging or requiring dealers to offer a mandatory green power option (MGPO) at the point of sale for EVs. Indeed, combining EVs and renewable electricity policy may not only make it more technically and economically feasible (5), but it may also make it more socially acceptable to consumers.

Surprisingly, with the exception of Norway and Sweden, there was no significant difference between WTP in renewables and hydropower, which is unexpected based on previous research into renewable electricity WTP (33–35), where WTP for hydro is typically found to be significantly less than other renewables. Even in Norway and Sweden, the WTP for hydro is only marginally less than their WTP for renewable fuels. So while consumers were perhaps overly generous when it came to paying extra for non-fossil and non-nuclear, they did not distinguish between hydro and renewables, just so long as the source was sufficiently clean.

Furthermore, there was substantial variation between the countries for both the WTP for renewables, hydro and nuclear. First and foremost, Denmark and Finland are substantially less willing to pay for renewable or hydro sources. We believe that the cause for this is that the other three Nordic countries have >98% CO_2-free electricity supply, and thus demand higher standards of clean electricity, whereas Denmark and Finland have substantially less clean electricity production (36). Additionally, specific to Denmark, though it has invested substantially in wind energy and prides itself on being green, recent literature has found Danes to "passively green", and less knowledgeable about the environment than it would like to think it is (37,38). At the same time, Denmark is one of the two countries, along with Iceland, with a negative WTP for nuclear-sourced electricity. Neither of these countries have nuclear generation (36), and perhaps consumers dislike the prospect of adding nuclear generation. Notably, the disutility of nuclear is markedly higher in Iceland, possibly because consumers are used to having ample hydro and geothermal power, and concerns about nuclear safety on an island. For the remaining three countries, the effect of nuclear compared to fossil fuels is not significant, implying that they may be ambivalent about the nuclear currently in their system.

Finally, we found that the WTP for adding V2G capability to EVs was only significant for two countries, Norway and Finland, both of which were positive. Such a result was unexpected, and we are unsure why these two countries in particular valued V2G capability. One hypothesis is that that Norway has greater experience and education with EVs, possibly leading to more comfort and familiarity for using the EVs as storage and an extra revenue stream. Secondly, Finland may value the increased reliability V2G may offer, given the increased concern over energy security, as well as historical connection to technology and communication development. Nonetheless, the values are only somewhat high, as they are equal to adding a range of 26 and 34 km to an EV for Finland and Norway, respectively. Additionally, unlike EV attributes, WTP for V2G does not fit the pattern of the policy context of EVs – thus, promoting EVs may not necessarily lead to increased knowledge of V2G.

Troublingly for those who support V2G as means to accelerate EV diffusion, the remaining three countries had no additional WTP for V2G. While the WTP for Finland and Norway represent the discounted revenue over 3-6 years (implying some slight over discounting), the remaining three countries were much more skeptical of the potential revenues of V2G, or perhaps especially concerned about battery degradation. Though the literature may espouse of the benefits of V2G, consumers in Iceland, Sweden, and Denmark did not find V2G convincing. Thus, perhaps the benefits of V2G should be better translated into the potential economic benefits, and further work should be done to educate the value of V2G to consumers, particularly within these three countries. Indeed, we found that less than 10% of consumers had heard of V2G before taking the survey, and there was surprisingly no statistical difference in the valuation of V2G capability between those who had or hadn't heard of V2G before.

5. Conclusion

In conclusion, compared to previous studies we have found through our choice experiment across Denmark, Finland, Iceland, Norway and Sweden that certain attributes of EVs are more strongly valued, such as driving range or recharging time, whereas others, such as acceleration, are not as strongly valued. Perhaps the demand for higher range and lower recharging time (and lack of demand for acceleration) is the result of characteristics specific to the consumers in the Nordic region. On the other hand, our results imply that these attributes vary between countries that could correlate to EV knowledge and background policy context. Thus, future research could investigate whether increases in general consumer knowledge, or pro-EV government signaling (like tax exemptions), leads to greater familiarity with specific attributes, and consequently higher WTP for those attributes.

Moreover, our results show that consumers have very high (and perhaps unrealistic) WTP for the clean sourcing of the electricity used to charge their hypothetical EVs. On the other hand, curiously, we found no difference between more distributed renewable sources (such as wind and solar) and hydro sources, implying that both are “green enough” for consumers. We also show that the value of V2G divorced from onerous contracts is positive and significant, but only for two of the countries, Norway (€5,200) and Finland (€4,000). Adding V2G capability to EVs in these two countries may be a cost-effective means to increase EV adoption, given that the cost of converting an EV to be V2G capable is likely substantially lower than these values. But, for other countries, V2G valuation remains near zero, and may be hindered by lack of consumer knowledge of the benefits, as this is very heavily discounting future potential revenues by both consumers who had knowledge of V2G previously and those that did not.

For those who are interested in accelerating the diffusion of V2G capabilities, especially as a means to increase EV adoption, as well as a means to improve renewable grid integration and overall grid efficiency, our findings underscore the essential need for greater consumer education of the technology. Given that 90% of the survey respondents had not heard of V2G before taking the survey, it is perhaps unsurprising that WTP for V2G capability for some countries is zero. Similarly, given the hypothesis that national EV policy influences consumer knowledge and valuation, the lack of visible V2G policy may also implicate the limited WTP for V2G capability. At the same time, consumers tend to discount future savings quite drastically (30,31), so perhaps other, less financially focused means of engaging consumers should also be investigated, such as more novel applications like vehicle-to-home (V2H) or vehicle-to-X (V2X).

On the other hand, it may be the perceived costs of V2G, such as the burdens of planning trips in a poorly designed system, may be limiting the value of V2G to consumers (39,40). In short, for V2G to successfully diffuse across consumers, both the benefits need to be made clearer, as well as limiting potential costs, and further research should investigate how specific attributes of V2G impact consumer preferences.

In sum, for both EVs and V2G, clear policy signals would improve consumer knowledge of the technology and increase valuation of the respective attributes. With this in mind, company advertisement and stronger and more conspicuous policies (such as more visible V2G pilot projects or giving EVs free bus lane access) may be very beneficial in increasing consumer knowledge and demand for these technologies. In turn, this could ease diffusion of the technologies as WTP increases. Thus, future research should investigate how government leadership, particularly with V2G, influences consumer preferences.

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Appendix 1: Demographic details of survey respondents

		Age			Gender			Total
		< 30 years	30-60 years	>= 60 years	Male	Female	Other	
Denmark	***Total***	**192**	**499**	**229**	**516**	**395**	**9**	**920**
	Random sample	164	396	219	433	338	8	779
	Non-random sample	28	103	10	83	57	1	141
Finland	***Total***	**194**	**550**	**158**	**508**	**386**	**8**	**902**
	Random sample	163	468	154	423	355	7	785
	Non-random sample	31	82	4	85	31	1	117
Iceland	***Total***	**204**	**369**	**19**	**231**	**352**	**9**	**592**
	Random sample	117	303	19	167	266	6	439
	Non-random sample	87	66	0	64	86	3	153
Norway	***Total***	**234**	**457**	**172**	**458**	**396**	**9**	**863**
	Random sample	224	405	166	418	369	8	795
	Non-random sample	10	52	6	40	27	1	68
Sweden	***Total***	**178**	**497**	**153**	**479**	**340**	**9**	**828**
	Random sample	174	425	150	415	326	8	749
	Non-random sample	4	72	3	64	14	1	79